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Geospatial Inventory of the Galakand Forestry Area Utilizing GIS Database and Remote Sensing Techniques

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This study investigated the dramatic reduction of forested areas in Azerbaijan, exceeding 50% over the past two centuries, largely due to increased wood production. Focusing on the period between 1880 and 1990, it analyzed the impact of timber harvesting on the composition of dominant tree species, with a special focus on beech trees, in the Galakand forestry area. Utilizing GIS databases and remote sensing techniques, the research assessed the changes in forest cover and species distribution, highlighting the critical transition from lush beech and oak forests to areas dominated by hornbeam, east hornbeam, oak-hornbeam, and juniperus-bush light forests. The study demonstrated the negative consequences of historical overexploitation, advocating for forest farming practices that promote the recovery and preservation of native forest ecosystems. Key findings revealed a marked decline in valuable wood species due to intensive logging activities, particularly between 1880 and 1914, and the detrimental effects of forest renewal cabins established from 1930 to 1970. The outlined measures in the study highlighted that the forest primarily comprises wooded areas (reserves with a completeness of 0.1-0.2, clearings, and clearings), non-forest lands repurposed as pastures and forested pastures with a density ranging from 0.3 to 0.4. Overall, the findings underscore the importance of sustainable forest management practices to reverse the adverse effects of historical overexploitation and preserve the biodiversity of Azerbaijan's ecosystems. The paper emphasized the necessity of sustainable forest management to reverse the damage and protect Azerbaijan's biodiversity to enhance measures for sustainable forestry, along with the critical role of advanced GIS and remote sensing in monitoring and conserving forest resources.

Keywords: Azerbaijan, forestry, GIS, remote sensing, sustainable forest management, biodiversity, deforestation, conservation, geographical conditions.

INTRODUCTION

***Background*:** Azerbaijan's forest coverage corresponds to approximately 11.8% of its total area, spanning 1,213.7 thousand hectares within the country's forest reserve. Over the past few decades, increasing human activities have further diminished the already limited forest coverage in Azerbaijan. Deforestation and the alteration of tree species are exacerbated by the competition between trees and shrubs. Shrubs not only act as substitutes for deteriorating forests but also indicate ecotopes suitable for artificial afforestation (Bazha *et al*., 2019). Forests in Azerbaijan hold significant economic importance, serving as a valuable resource for firewood, timber, and non-woody materials. Wood constitutes the primary output from forests, used in the production of over 20,000 items. To meet the demands of the population and the national economy, it is crucial to ensure the restoration and preservation of forests and their sustainable utilization. Enterprises dedicated to forest preservation activities and regional forestry have been established (Anuchin, 1991).

The organization of forestry activities encompasses administration, sustainable utilization, growth, and expansion of forests, all aimed at restoring and preserving forested areas. Thorough examination, precise bookkeeping, and meticulous assessment are essential in addressing these concerns and implementing necessary measures (Buzmakov *et al*., 2009). The Forest Inventory and Analysis (FIA) program, conducted by the U.S. Forest Service, carries out a comprehensive three-phase forest inventory and monitoring initiative nationwide

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(Bechtold and Patterson, 2005). The study employed a post-stratification scheme using remotely-sensed data to reduce estimation variability. Azerbaijan's national development strategy for forests focuses on expanding the forest area through silviculture and natural regeneration operations targeting valuable tree species. Each year, silviculture activities cover an area of 2.5-3.0 thousand hectares, while promotion of natural regeneration is carried out on 7.0-7.5 thousand hectares. Approximately 10,000 hectares of new forest stands are converted into woody areas annually.

Natural regeneration on transferred forest lands is 2.5-3.0 times more significant than artificially generated forest plantations (Amirov, 1997; Mammadov, 2002). Natural regeneration requires fewer labor, materials, and financial resources compared to artificial methods. Moreover, naturally regenerated forests exhibit greater productivity and resilience against external environmental influences, making them more manageable and predictable in their development dynamics, as opposed to artificial forests (Parhizkar *et al*., 2011). To achieve successful natural regeneration, it is crucial to ensure optimal growing conditions and eliminate detrimental impacts from external sources (Halil *et al*., 2015).

***Remote Sensing and GIS Technology*:** Forests play a vital role in human and ecosystem health, with their management relying on reliable data from natural resource monitoring systems. Remote sensing and Geographical Information System (GIS) techniques are widely used for modeling (Risna *et al*., 2023; Zagalikis, 2023). Integrating remote sensing (RS) with ground-based inventories can enhance efficiency. Lister *et al*. (2020) extensively utilized remote sensing technology in the U.S. Forest Inventory and Analysis (FIA) program, which can serve as a valuable case study for countries seeking to improve their forest inventory programs. Space photography plays a crucial role in investigating geographic conditions over vast areas of the Earth, resource exploration, and environmental conservation efforts. Chang Space photography involves surveys conducted beyond the Earth's atmospheric layer using spacecraft, artificial satellites, interplanetary automated stations, and controlled orbital space stations (Mehdiyev, 2005). These surveys transmit space images to Earth through the radio-television system (Ibrahimov, 2016).

Aerial photography captures extensive landscapes spanning hundreds of square kilometers from a space perspective. Vegetation photo plans are created using aerial images obtained from various aircraft, such as airplanes, helicopters, drones, or balloons, at close distances of 1 to 3 kilometers from the Earth's surface. Satellite photos are utilized to create comprehensive maps of forest vegetation, desertification, geomorphology, and other factors over large regions (Kotova, 2012). Geographic Information Systems (GIS) programs universally incorporate capabilities specifically tailored for the analysis of geographical data, encompassing raster and vector formats, as well as attribute data that includes categories, colors, numerical values, and measurements in absolute and relative terms. Analytical analysis functions supported by GIS were used to examine the forest structure of the Galakand forestry territory. The abbreviation "Cartography and Geographic Information Society" refers to a professional organization associated with the study and application of maps and geographic information. It is essential to note that, similar to other aerial photographs, the scale of satellite images depends on the distance between the satellite and the Earth's surface. For example, if the image used to determine the location of the Galakand forest area (Fig. 1) is captured from an altitude of 45 km, the image used to calculate the borders and extent of the forest is obtained from an altitude of 14 km (Fig. 2).

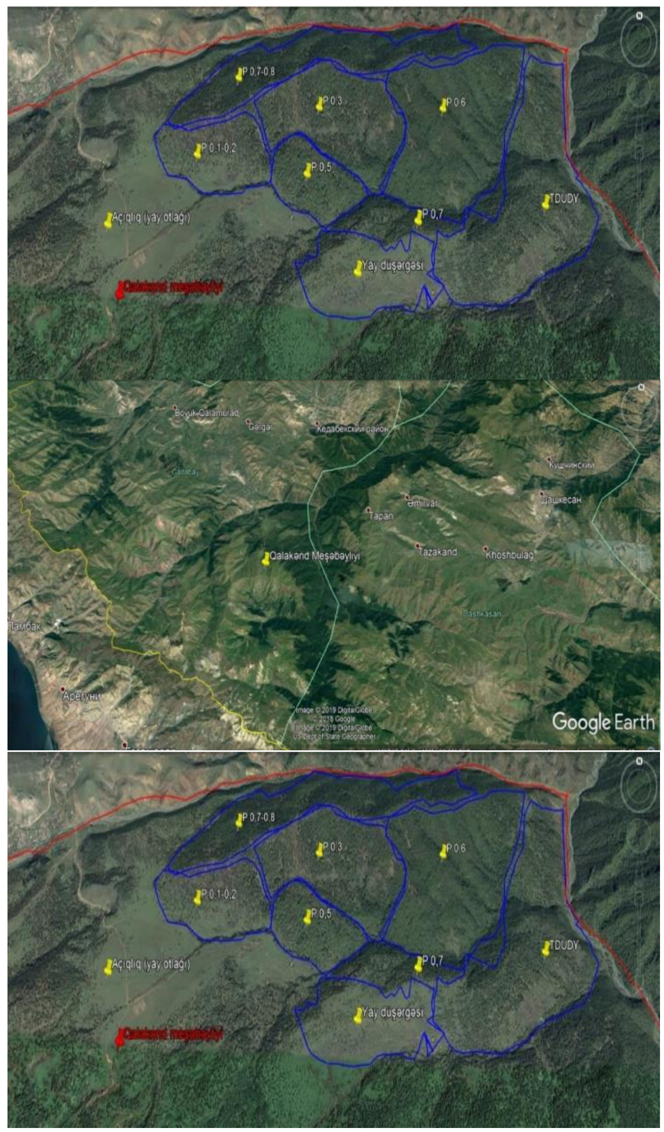
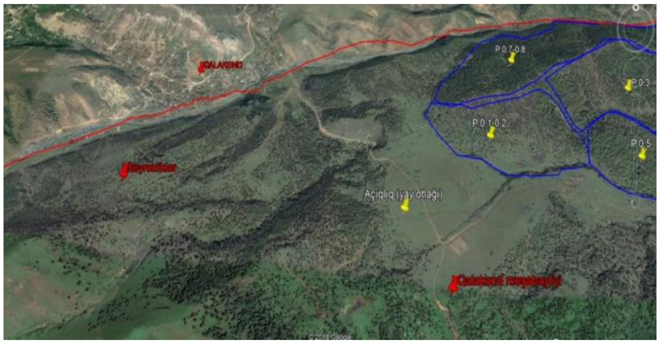


Figure 1. View on the territory of the Galakand forestry from a height of 45.7 km above sea level.

A. The absolute altitude above sea level is 5.62 km



B. The absolute altitude above sea level is 4.26 km.

Figure 2. (A) Giving closed contours of the forest area by filling the territoryof the Galakand forestry by land categories.

Figure 2. (B) Cattle farmer's summer camp (H=1,77 км)

MATERIALS AND METHODS

Study Area**:** The study explores the Gedabek Forestry (DF), a 25,555 hectare area in Azerbaijan's Gedabek district. The forestry department's administrative offices are in the city's central section. The study focuses on 9770 hectares of the Galakand forests of the Gadaebek DF, located in the western part of the republic. The forests cover 40 km in the north-south direction and 60 km in the west-east direction, influenced by climatic and soil conditions.

Materials**:** The study utilized space cartography to explore geodata, gathering data from various sources like LANDSAT, satellites, and platforms like Google Earth and Google Maps. The findings will be used for forest monitoring, cadastre, management, and restoration. The research also employed traditional forestry research methods and specialized remote sensing and GIS data for forest structure design, similar to Anuchin (1991) described. Additionally, the study incorporated the specialized methodology of remote sensing and GIS data, as outlined by Zhurkin (2009). The forest structure design relies on remote sensing techniques and GIS technology, utilizing inventory and taxation data obtained from satellite imagery. The provided image is a LANDSAT image from 2019, sourced from Digital Globe and authorized by the US Department of State Geographer.

RESULTS

The study on Azerbaijan's forest management, underpinned by a blend of vector and raster modeling along with satellite imagery, unfolds significant findings regarding the state and management of forests in the region. Here, we delve into the intricate details of these findings and their implications for sustainable forest management. According to vector modeling, the forestry territory is encompassed within a polygon with a perimeter length of 99.6 km. The area, as determined by the raster model, is 9770 hectares. The allocation of the forestry area by different categories was established by considering the distinct characteristics of each category and their corresponding colors (see Fig. 2 and Table 1). Upon analyzing the table, it is evident that the forestry area encompasses a total of 8,255 hectares (84.4%) of forest lands, with 62.6% of this area being covered by actual forest. The proportion of non-wooded areas within forested lands is 15.0% (1463 ha), while clearings and open spaces account for 0.6% (total15.6%).

A noteworthy observation from this study is that livestock grazing, particularly on non-forested forest areas, has emerged as a significant factor contributing to the destruction of forests. Out of all the non-forested forest areas, 15.6% (1515 ha) are mostly occupied by summer pastures and rural pastures, which accounts for 13.05% of the total area. The satellite photographs provide unequivocal evidence that the primary factor contributing to the destruction of forests is the practice of livestock grazing on these lands. This finding highlights the need to address the issue of livestock grazing and implement appropriate measures to protect forested lands from the detrimental effects of grazing animals.

The results of modeling the forest area based on attribute information are presented in Table 3, 4, 5 and 6. The categorization and visualization of forest area coverage by species were decided based on factors such as surface

Table 1. Distribution of the total area of Galakand forestry by land categories. (Gedabek DF).

Unit of measurement	The total area of the forestry	Forest lands						Total forest lands
		Covered with forest		Unclosed by the canopy	Area not covered by forest			
		Total area	Including artificial		Sparse woodlands	Wastelands	Total treeless	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Ha	9770	6122	74	26	1463	644	2107	8255
%	100	62,6	0,8	0,2	15,0	6,6	21,6	84,4

Table 2. Distribution of the total area of Galakand forestry by land categories. (Gedabek DF)

Non - forest lands								Common non - forestlands
Grounds			Unused lands					
Crops	Hay making	Hayfield	Under water	Roads	Buildings & nurseries	Stream & ravines	Rocks, stone avalanches	
10	11	12	13	14	15	16	17	18
9	52	1273	17	6	4	84	70	1515
8	0,5	13,05	0,2	0,05	0,02	0,9	0,7	15,6

illumination, distribution patterns of forest species, and the analysis of vector and raster data. As an illustration, hornbeam forests are primarily found along the Galakand River in the northern region of the district. The Eastern oak woods are found at elevations ranging from 1700 to 1950 meters. The majority of the remaining area is covered by beech forests, accounting for 70.2% of the territory (FAO, 2010).

Table 3. Distribution of forest area in the GalaKand forestry by species (%).

Forest breed	Square	
	ha	%
Beech (Fagus orientalis)	4316	70,6
Oak (Quercus macranthera)	1129	18,4
Hornbeam, (Carpinus caucasica)	596	9,7
Other breeds	81	1,3
Total	6122	100

Table 4. Indicators of taxation of the area covered by forest in the Galakandforestry.

Forest - forminggenus	Area, ha	Average bonus	Average age, years	Average fullness	Averages tock per 1ha, m^3
Beech	4316	III, 1	102	0,56	215
Oak	1129	IV, 3	85	0,59	75
Common hornbeam	596	III, 9	70	0,54	130
Other breeds	81	III, 8	65	0,49	80
Verage forest cover	6122	III, 4	84	0,55	134

Table 4 presents the primary indices of forest area taxation categorized by species. Beech woodlands exhibit elevated indicators (United Nations Conference on Environment and Development, 1992). Forestry experts utilize the distribution of trees by age classes and occupancy to develop the primary forestry metrics. Specifically, the condition of the trees and the element of time are used as the foundation. Table 5 displays the allocation of forest area according to different species and depicts the forestry area (53.4% or 3270 ha) is primarily covered by trees with a density of 0.3-0.4.

The majority of the forest consists of trees that are in their middle stage of growth, accounting for 73.7% or 4508 hectares of the total area. The percentage of juvenile trees is 2.0% and the percentage of mature trees is 2.1%, including elderly trees. The presence of a small number of young trees suggests a lack of natural regrowth in the forests. Similarly, the presence of only a few mature and old trees suggests that the forests have been heavily exploited recently. The proposed forestry measures primarily encompass wooded areas (reserves with a completeness of 0.1-0.2; clearings and clearings), non-forest lands utilized as pastures, and forested pastures with a density of 0.3-0.4. On the area of 1,463 hectares of the forestry territory, sparse woodlands with a completeness of 0.1-0.2 are distributed, not related to the area covered by forest.

Table 5. Distribution of the area covered by forest in the Galakandforestry (%).

Forest - forminggenus	Area by completeness, ha/%				
	0,3-0,4	0,5-0,6	0,7-0,8	0,9-1,0	Total
Beech	2580	1166	557	13	4316
	59,78	27,02	12,9	0,3	100
Oak	550	480	73	26	1129
	48,7	42,5	6,5	2,3	100
Common	109	346	125	16	596
hornbeam	18,3	58,1	21,0	2,6	100
Other breeds	31	45	5	-	81
	38,3	55,6	6,1	-	100
Conclusion on	3270	2037	760	55	6122*
forestry	53,4	33,3	12,4	0,9	100

This detailed analysis of Azerbaijan's forest management challenges and opportunities reveals a complex interplay between forest biodiversity, land use practices, and conservation needs. The findings underscore the pressing requirement for a holistic management approach that balances ecological conservation with socio-economic needs. Implementing the proposed measures, especially those aimed at curbing livestock grazing and promoting forest regrowth, is crucial for the sustainable management and preservation of Azerbaijan's forest resources.

Table 6. Distribution of forest area by age groups of woodlands in the Galakand forestry (%).

Age stage	Square	
	Ha	%
Young trees	122	2,0
Medium - aged trees	4508	73,7
Adults	1362	22,2
Mature and old-aged	130	2,1
Completely covered withforest	6122	100

DISCUSSION

The objective is to organize, manage, and develop forests by creating forest structure documents, including plan-cartographic materials and descriptions of tree allocation. Forestry materials provide comprehensive information about forests and facilitate the assessment of tree values at any given moment. The items utilized in accordance with Geographic Information Systems (GIS) are employed in the zones as a contemporary construction strategy. Forest exploitation occurred in commercially viable locations that were in close proximity to the populace extensively exploited forests. The practice of "selective cutting" in the forest plateau region is frequently characterized by its arbitrary nature, with forests being removed in a haphazard and unregulated manner. Consequently, there were sufficient spaces in the plains that had been cleared of trees. The implementation of forestry activities in Azerbaijan commenced in a systematic manner in 1929-30 and persisted until the 1990s, with a decade-long interval for assessment and evaluation.

The forest stock changes in the Zayam forest plateau were exposed and evaluated using a comparative analysis of forest structure materials conducted in 1892, 1929-30, and 1990. The long-term monitoring conducted on the forest structure materials in the Zayam forest plateau in 1892, 1929-30, and 1990 reveals significant changes in the area of valuable forest-working species, particularly beech forests. These changes can be attributed to intensive exploitation over the past 120 years. Additionally, the monitoring confirms a relative decrease in oak forests. Simultaneously, there has been a substantial rise in the expanse of valleys, iron-black forests, juniper thickets, and shrubbery. While the natural regeneration of forests was guaranteed, the presence of intense livestock grazing hindered this process in numerous instances, leading to the formation of vacant fields, open spaces, and clearings. To prevent the decrease in the area of valuable forest-working species and their substitution by inferior species, the foremost requirement is the implementation of natural restoration.

The management and monitoring of forests play a crucial role in identifying both qualitative and quantitative changes in the forest stock and acquiring valuable information (Kalinin, 2007). The data collection technique for forests involves three distinct levels: satellite monitoring, aeromonitoring, and ground surveys (Komissarov *et al.*, 2005). Utilizing all three levels in conjunction is both more effective and crucial in obtaining comprehensive insights into forests. Data acquired by remote sensing, specifically aircraft monitoring, is utilized in intricate scenarios for analyzing interconnections, facilitating decision-making in routine operational environments, and more. It offers greater versatility for various tasks and is commonly utilized. In order to oversee such an intricate procedure, there must be efficient methods in place. GIS serves as a highly efficient management tool, effectively processing all spatial information, including remote sensing.The utilization of remote sensing, in conjunction with Geographic Information Systems (GIS), enables the ability to extrapolate findings across extensive regions and achieve specific outcomes at a reduced timeframe, as compared to alternative methodologies.

***Conclusion*:** The use of GIS monitoring and control enables the execution of cleaning operations on a total area of 9,770 hectares of Forest Lands in Galakand Forest Bay in DF. Remote sensing was utilized to develop forestry-farming solutions for a total area of 9770 hectares in the Forest Fund Lands of the forest district.

***Authors contributions statement*:** All authors conceived and designed the research, collected and analyzed the data, and wrote the manuscript.

***Conflict of interest*:** The authors declare that they have no conflict of interest.

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***Ethical statement*:** This research adhered to all ethical guidelines and standards. All experiments involving human subjects or sensitive data were conducted with proper consent and in accordance with ethical regulations.

***Availability of data and material*:** The data and materials used in this research are available upon request from the corresponding author.
***Code availability*:** Not applicable.
***Consent to participate*:** Informed consent was obtained from all individual participants included in the study.
***Consent for publication*:** The participants provided consent for the publication of the research findings.

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